STATUS OF THE AUTOMATED ACTIVATION OF GaAs PHOTOCATHODES AT PHOTO-CATCH*

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Abstract

Photocathodes based on the III-V seminconductor GaAs are used as photo-electron sources to supply spin-polarized electron beams for accelerator applications. In order to achieve sufficient electron yield, a thin surface layer of cesium combined with an oxidant is applied onto the cathode surface in a process called the cathode activation. It is typically done manually by an experienced operator. This contribution presents the current status in the development and testing of an adaptive algorithm for automated activation at the Photo-CATCH test stand.

INTRODUCTION

Spin-polarized electron beams provide the opportunity to probe a variety of physical systems, from magnetic materials and surfaces to the internal structure of particles and nuclei. These specialized beams can be produced by GaAs semiconductor photocathodes. Following a dedicated activation procedure, which will be addressed later, the GaAs cathodes are irradiated using a polarized laser with a fixed wavelength. Electrons emitted via the photo effect can then be extracted for the desired application.

The main research instrument at the Institue for Nuclear Physics (IKP) of Technische Universität (TU) Darmstadt is the superconducting Darmstadt Linear Accelerator (S-DALINAC) [1]. It is capable of providing both unpolarized and polarized electron beams, depending on the source used. The polarized electrons are created by the Spin Polarized Injector (SPIn) [2]. In order to enable research independent from the schedule of the S-DALINAC, a separate test stand was constructed: Photo-CATCH (Photo-Cathode Activation, Test and Cleaning using atomic Hydrogen) [3]. It features several XHV chambers for the handling of photocathodes, as well as a small beamline with different instruments used for the characterization of the produced electron beam. The photocathodes are prepared in the activaiton chamber, named after the process required for GaAs to achieve negative electron affinity (NEA) [4]. The procedure consists of the application of a thin layer of an alkali metal and an oxidant, in our case cesium (Cs), lithium (Li) and oxygen (O_2). This is typically done manually by an operator, following one of the established recipes, the so-called activation schemes. The quantum efficiency η is an important parameter to compare different activations, it measures the ratio of the outgoing electrons over the incoming photons. However, η shows considerable variation, even when following the same recipe [5]. In an effort to make the activation more reproducible, attempts to automate this process have been made. After a successful proof of principle, an adaptive algorithm was developed, capable of reacting to the different stages of the process [6].

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CATHODE ACTIVATION AT PHOTO-CATCH

Photo-CATCH

Of the multiple chambers at Photo-CATCH, only the Cathode Activation Chamber (CAC, Figure 1) is used during the activation procedure. A carousel holds the photocathodes and moves them through the chambers via external manipulators. Small heating coils enable heat cleaning between activations. Cesium (Cs) and lithium (Li) are applied to the cathode with dispenser rods, which release their material in a controlled and reproducible manner. Oxygen flows into the chamber from an external reservoir through a piezo-controlled leak valve, which causes several issues discussed below. A window on the bottom allows the light used for the generation of the photocurrent to enter and hit the cathode surface. The anode ring collects all produced photo electrons using a bias voltage.

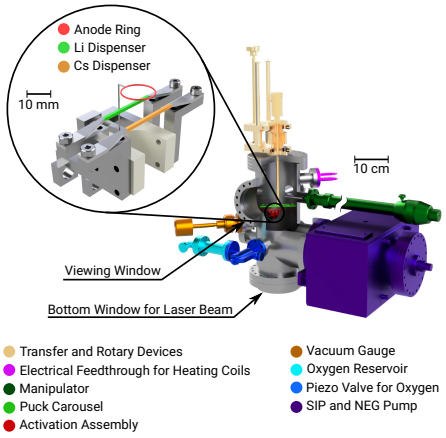

Figure 1: Cathode Activation Chamber (CAC) of Photo-CATCH, used for preparation and characterization of GaAs photocathodes. Figure taken from [7].

The activations discussed here follow the Co-Deposition scheme: Switching on the Cs supply prompts the photo current to rise into a first maximum, the Cs peak. After it has dropped to a specific fraction of the peak value, O_2 is added to cause the second, much higher and longer rise in

to a final plateau. Once it has been passed, both sources are deactivated and the procedure is complete.

Piezo-controlled Oxygen Valve

As indicated before, the piezo valve controlling the oxygen flow into the CAC has caused difficulties for both manual and automated activations due to its unreliable operation, yielding strongly varying results. They stem from several different sources, making them challenging to control directly. Piezo elements in general are known to suffer from hysteresis effects and for having a temperature dependence, the geometry of the valve opening is another contributing factor. To indirectly compensate for these, the voltage applied to the piezo valve was corrected by the operator in an iterative way. These empirical manual corrections could not be replicated by the algorithm, causing the cathodes activated automatically to receive vastly different doses of O_2, despite using the same settings for all activations. So both automated and manual activations stood to gain from an improved control of the oxygen flow, increasing the reproducibility of both, making the automation more robust and the manual ones easier to execute.

In order to achieve this, a tool is needed to bring the amount of oxygen inside the chamber to a setpoint and keep it there, while also being able to react to the aforementioned inconsistencies caused by the piezo valve. A PID controller is an established control loop scheme that fulfills all requirements. Also it can be implemented fully on the software side using only existing hardware at the experimental setup. The development of the PID contained some challenges, which will be discussed in the next section.

PID IMPLEMENTATION

Development

Generally, a PID controller uses a feedback loop based on a set of parameters to keep a process variable (PV) as close to a desired setpoint value (SP) as possible. The first step consisted of choosing the PV to represent the oxygen flow into the CAC. Among the available readouts the total pressure inside the chamber showed the most direct proportionality. While it is also influenced by other factors, such as the outgassing of the chamber walls and the material released by the Cs and Li dispensers, these contributions are at least two orders of magnitude smaller and are thus negligible for the PID.

Next, the step responses of the pressure inside the chamber following changes of 5 V in a range between 50 V and 250 V were recorded. This was challenging for two reasons. Before the step the pressure is not constant, but exhibits a slow, linear rise. The first part of the step itself occurs quickly, after which the pressure approaches its saturation point in an asymptotic behavior. In order to extract the values needed to calculate a first estimate for the PID parameters, both the saturation before and after, as well as the step itself, were approximated by linear functions.

Implementation

When the PID was tested experimentally, the predetermined control parameters were unable to achieve the desired stable and contained oscillation around the setpoint. Instead it tried to achieve a value slightly below the actual target. Moreover, in some cases the oscillation became unstable after the setpoint was reached, escalating such that the amplitude increased rapidly before shutting of due to exceeding the pressure safety thresholds. This led to a measurement series in which different parameter settings were manually tested in varying pressure ranges. The resulting, manually optimized PID values were able to increase the pressure to the setpoint and stabilize it there, but only within a certain pressure region, not encompassing the full operation range. Hence, four different PID parameter sets were determined manually for their respective pressure regions.

EXPERIMENTAL RESULTS

The final step was an activation of GaAs cathodes in the CAC using the developed PID oxygen control, and a reference measurement during which the oxygen was controlled manually.

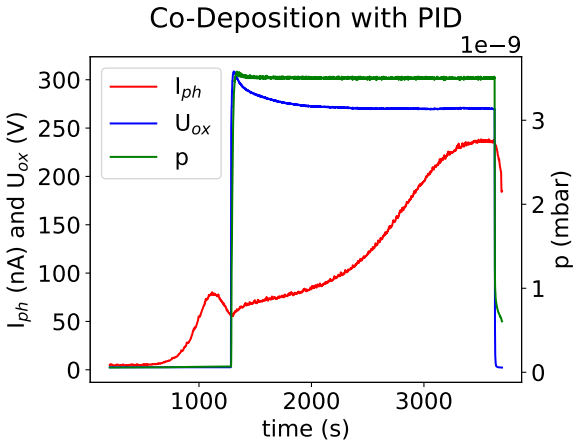

Figure 2: Cathode activation using the oxygen PID controller. The pressure setpoint for oxygen of 3.5×10^{-9} mbar was reached and held with very little deviation. Graphic taken from [8] and adapted.

The PID activation can be seen in figure 2. The predetermined setpoint of 3.5×10^{-9} mbar for the pressure during the oxygen stage was reached quickly and kept consistently. The voltage applied to the piezo valve decreases over time, visualizing the saturation of the oxygen content of the chamber. This activation resulted in a quantum efficiency of η =3.40(8) % after 3625 s. The reference activation achieved η =3.33(6) % after 3800 s, both results are listed in Table 1. Comparing them to past activations [5] indicates an increase in consistency for the activation process.

CONCLUSION AND OUTLOOK

One of the challenges for automated activations of GaAs photocathodes using O_2 as an oxidant, supplied by a piezo

Table 1: Activation Results

Mode	η (%)	Duration (s)
PID	3.40(8)	3625
Manual	3.33(6)	3800

valve controlled reservoir, could be solved by developing and implementing a PID controller regulating the flow of oxygen into the activation chamber. It utilizes the pressure change caused by the oxygen as the process variable and is able to stabilize the pressure level to the setpoint with minimal deviations. Now the PID needs to be integrated into the automated activation procedure, with the goal to increase its consistency.

REFERENCES

[1] N. Pietralla, "The Institute of Nuclear Physics at the TU Darmstadt", *Nucl. Phys. News*, vol. 28, no. 2, pp. 4-11, July 2018. doi:10.1080/10619127.2018.1463013

[2] Y. Poltoratska *et al.*, "Status and recend devepolments at the polarized-electron injector of the superconducting Darmstadt electron linear accelerator S-DALINAC", *J. Phys. Conf. Ser.*, vol. 298, no. 1, p. 012002, 2011. doi:10.26083/tuprints-00020677

[3] N. Kurichiyanil, "Design and construction of a test stand for photocathode research and experiments", Ph.D dissertation, IKP, TU Darmstadt, Darmstadt, Germany, 2017. doi:10.26083/tuprints-00005903

[4] W. E. Spicer and R. L. Bell, "The III-V Photocathode: A Major Detector Development", *Publ. Astron. Soc. Pac.*, vol. 84, p. 110, Feb. 1972. doi:10.1086/129256

[5] M. Herbert, "Electron emission from GaAs photocathodes using conventional and Li-enhanced activation procedures", Ph.D dissertation, IKP, TU Darmstadt, Darmstadt, Germany, 2022. doi:10.26083/TUPRINTS-00020707

[6] M. Engart, "Adaptive algorithm and interface for automated activations of GaAs photocathodes", M.Sc. thesis, IKP, TU Darmstadt, Darmstadt, 2024.

[7] T. Eggert, "Development of a Cryogenic DC Photoelectron Gun for GaAs Cathodes with Increased Charge Lifetime", Ph.D dissertation, IKP, TU Darmstadt, Darmstadt, Germany, 2023. doi:10.26083/TUPRINTS-00023275

[8] R. Petry, "PID-Regelung der Sauerstoffzufuhr für die Aktivierungskammer von Photo-CATCH", B.Sc. thesis, IKP, TU Darmstadt, Darmstadt, 2025..